

Review by Dr. Tom Myers, Independent Hydrologist

Scope of Work

Myers' review focuses on the indirect impacts caused by operating the Back-Forty Mine on existing wetlands in the project area. The indirect impacts of interest are those related to dewatering drawdown, which could lower the water table beneath wetlands thereby causing those wetlands to drain faster when filled with surface water or disappear altogether if the wetland water surface connects to the water table. Dr. Myers' analysis involved an assessment of the predicted drawdown on wetlands and a review of the groundwater modeling of those impacts. One concern includes how the modeling conceptualized the wetlands, meaning the level of connectivity with surface water. Another concern includes the prediction of the extent of the drawdown, as modeled.

Conclusion

"The application acknowledges direct impacts to 11.22 acres and indirect impacts to 17.17 acres of wetlands. The review presented in this memorandum shows that indirect impacts will occur to far more than 17.17 acres because the modeling underestimates the extent of the groundwater drawdown. The Back Forty mine will have much greater indirect impact on wetlands than acknowledged in the permit application." - Tom Myers

Technical Memorandum: Review of the Indirect Impacts of the Wetland Permit Application, Back Forty Project

Dr. Myers is a hydrologic consultant who works with conservation organizations and others on mining, natural gas, and water rights development, with specific interests in contaminants and mine dewatering. Myers has degrees in Hydrology and Hydrogeology and works with conservation organizations and others on mining, natural gas, and water rights development, with specific interests in contaminants and mine dewatering.



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Technical Memorandum

Review of the Indirect Impacts of the Wetland Permit Application Back Forty Project

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Prepared for: Upper Peninsula Environmental Coalition

Executive Summary

This memorandum reviews technical aspects of the wetland permit application for the Back Forty Project. The focus is on indirect impacts to wetlands. An indirect impact is an elimination of saturation during spring growth seasons or fluctuations that deviate from pre-development.

Indirect impacts to wetlands are underestimated in three ways. First, the groundwater model used to simulate groundwater flow through the area uses constant head boundaries around the model perimeter in ways that allow extra water to flow through the system. This resulted in about 30% more water flowing through the system during steady state calibration than should have flowed. This results in calibrated conductivity values that are much too high, which limits the drawdown near the wetlands.

Second, groundwater levels beneath the wetlands were artificially prevented from being drawn down by the dewatering because the model simulated the wetlands as River boundaries which provides too much water to the model domain. In other words, the model creates water that may or may not be there, and simulates a hydraulic connection in such a way as to limit the extent of drawdown. This allows the model to show almost no drawdown beneath wetlands that will probably end up dry, at least seasonally, when they otherwise are wet.

Third, the direct modeling of wetlands, whether in the valley or in the uplands, assumes that water in the wetlands can seep into the ground through the bottom of the wetland as easily as it can percolate into a river bed or onto unsaturated ground. This modeling ignores the fact that the bottom of wetlands would be full of fine sediments that would impede the flow through the bottom of the wetland. This flow impedance would occur regardless of the groundwater level beneath the wetland. Currently, the modeling allows water to flow unimpeded to the groundwater, which prevents the drawdown cone from spreading.

The application acknowledges direct impacts to 11.22 acres and indirect impacts to 17.17 acres of wetlands. The review presented in this memorandum shows that indirect impacts will occur

to far more than 17.17 acres because the modeling underestimates the extent of the groundwater drawdown. The Back Forty mine will have much greater indirect impact on wetlands than acknowledged in the permit application.

Introduction

This technical memorandum reviews the Permit Application – Back Forty Project (MDEQ/USACE Joint Permit Application for: Wetland Protection, Inland Lakes and Streams, Floodplain presented by Aquila Resources to the Michigan Department of Environmental Quality (MDEQ). The application was prepared by Foth, Stantec, and King and MacGregor Environmental. The primary review is of the Indirect Impacts report (Foth and King 2017) and the groundwater modeling report (Foth 2015). References within this review to Volume (Vol) are to the Volume of the application. Vol 1 includes a formal Joint Permit Application (JPA).

This review focuses on the indirect impacts caused by operating the Back-Forty Mine on existing wetlands in the project area. The indirect impacts of interest are those related to dewatering drawdown, which could lower the water table beneath wetlands thereby causing those wetlands to drain faster when filled with surface water or disappear altogether if the wetland water surface is connected to the water table. The analysis would involve an assessment of the predicted drawdown on wetlands and a review of the groundwater modeling of those impacts. This memorandum does not review the wetland delineation reports, or comment on the delineated areas or the methodology.

The estimate of indirect impacts involves hydrologic modeling of each wetland. It involves consideration of the drawdown beneath the wetland caused by dewatering for the mine. Foth (2015) estimated the drawdown using a numerical model completed using the MODFLOW computer code. In addition to the report, Foth (2015), I obtained and analyzed the MODFLOW input files using the GWVistas graphical unit interface (GUI). This memorandum reviews model report and input code, but only with respect to how the model predicted indirect wetland impacts. It is not a complete model review.

The JPA states the project would directly impact approximately 11.22 acres of wetlands by excavating about 5.31 acres and placing fill on about 5.91 acres (JPA, p 2 of 15). It also states the project would indirectly impact approximately 17.17 acres of wetland, of which 4.16 acres is emergent and 13.01 acres is forested (Id.). The JPA has numerous tables and figures attached supporting aspects of the application. JPA Figure 3-1 shows areas of direct and indirect wetland impacts. Figure 1 shows six areas of indirect impacts, with the largest on the west being for 6.15 acres due to “loss of surface water inflow”, presumably from pit excavation intercepting

the stream. The others are also due to a “loss of surface water impacts. Figure 2 shows the east side of JPA Figure 3-1 which shows several indirect impact areas of loss of surface water flow due to water balance model.

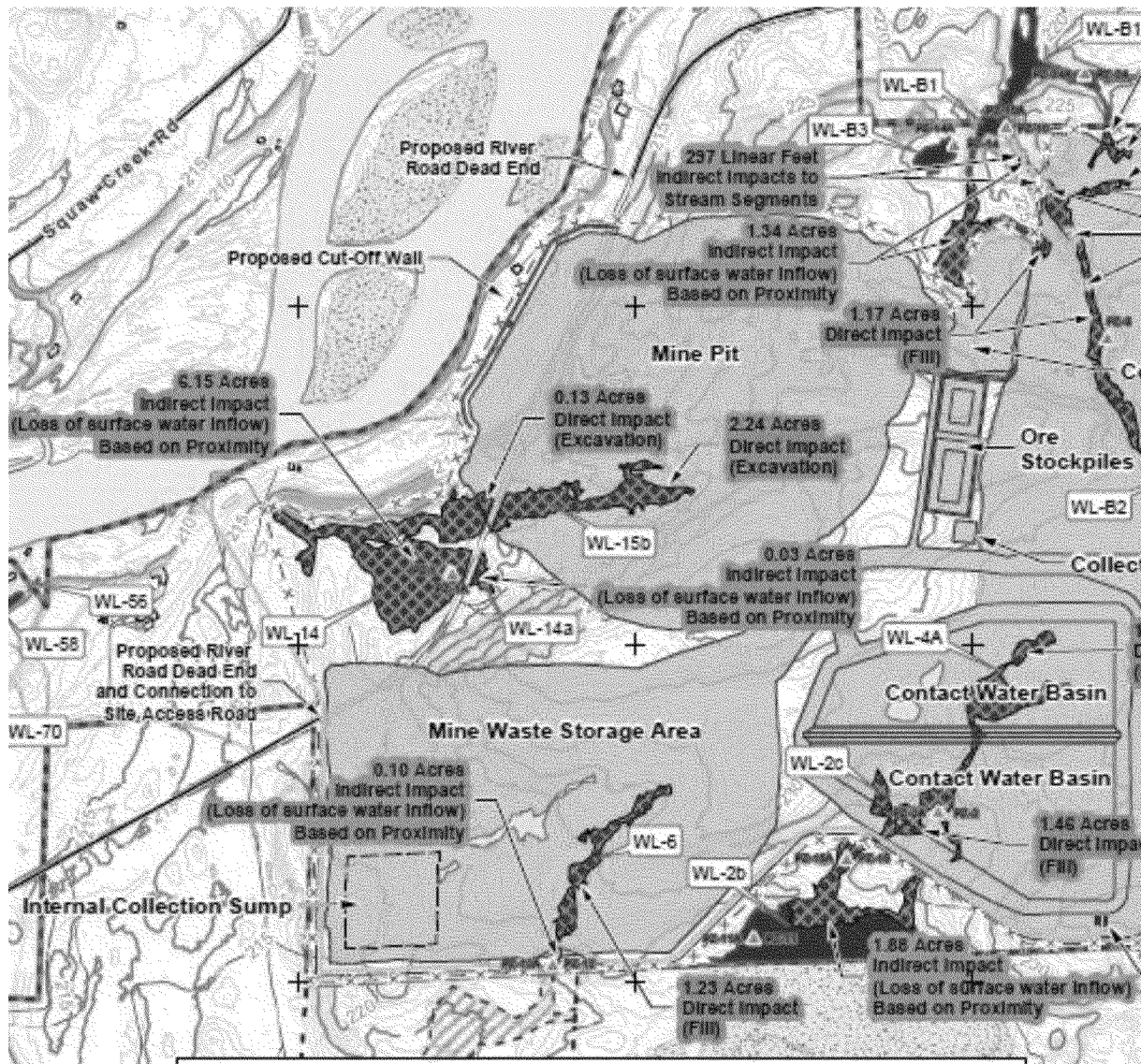


Figure 1: Western portion of the Joint Permit Application Figure 3-1 showing wetland impacts.

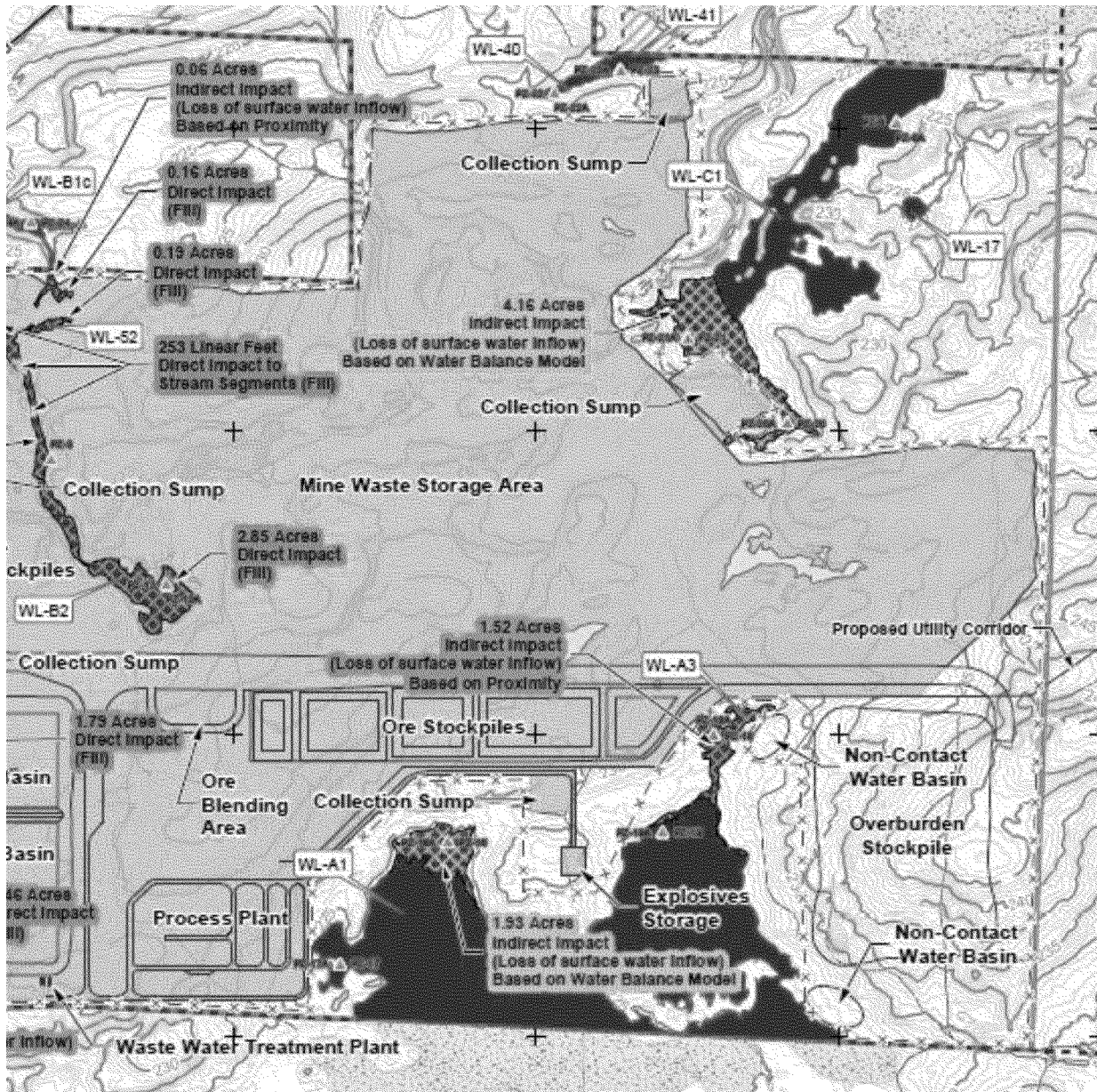


Figure 2: Western portion of the Joint Permit Application Figure 3-1 showing wetland impacts.

Analysis of Indirect Impacts Report (Foth and King 2017)

Indirect impacts occur if there is no saturation at the soil surface during the spring growing season or if seasonal fluctuations deviate from pre-development season fluctuation (Foth and King 2017, p 21). Significant drawdown beneath the site may not cause an indirect impact because seasonal runoff and precipitation could make up the increased loss to infiltration.

Foth and King (2017) distinguish between upland and valley wetlands, with upland wetlands having a primarily a downward groundwater hydraulic gradient and valley wetlands having an upward gradient at least during parts of the year. Upland wetlands would be recharge source and valley wetlands would be groundwater sinks. Upland wetlands would receive their water from direct precipitation and runoff. Upland wetlands would also be separated from underlying groundwater by unsaturated soil.

Foth and King (2017) present hydrgraphs of water levels from two levels beneath some of the valley wetlands. These show that vertical gradient fluctuates around zero, meaning there are periods during which the groundwater discharges to the wetland. The deeper piezometers fluctuate less than the shallow piezometers, in the estimation of vertical gradient. The general conceptual model that wetland water elevations increase during late spring/early summer is correct.

Foth and King (2017) use groundwater elevations and depths to groundwater as determined using the groundwater model of Foth (2015) which I review below. The conceptual model for wetland water balance presented in Figure 5-9 is not incorrect, in that it includes the necessary factors to account for precipitation, runoff into the wetland from the watershed above, evapotranspiration, discharge through the bottom to groundwater, and changes in water storage (the water level in the wetland). If the water table is below the bottom of the wetland, the model assumes seepage to groundwater; this is the largest error in the analysis as will be described.

The water balance equation (Foth and King 2017, p 9) does not account for interflow to the wetland. It accounts for runoff and direct precipitation. It is possible that interflow is part of runoff. This should not cause significant errors.

Anything that decreases flow to the wetland causes an indirect impact. In addition to drawdown preventing groundwater inflow to the wetland, the capture of contact water would decrease surface water runoff to the wetland (Foth and King 2017, p 11). The accuracy of these estimates is not assessed here.

They estimated runoff to the site as 6 inches per year based on a 1974 USGS study (Foth and King, 2017, p 12). This is reasonable and if used consistently would not overestimate runoff. They considered using the NRCS method (Foth and King 2017, p 13), but this would have been inappropriate. The NRCS method is for storm events, not annual runoff.

Seepage to groundwater was modeled partly with the MODFLOW model (Foth 2015) and partly with an unsaturated flow model. The wetlands were modeled as a RIVER boundary in

MODFLOW, which is inappropriate as discussed below. The RIVER boundary provides too much water to the groundwater and limits the drawdown beneath the wetland. While Foth (2015) claims the amount is limited to the average recharge rate for the area, the reality is that they overestimate the vertical conductivity through the bottom of the wetland, which allows the RIVER boundary to provide water to the groundwater table and prevent it from receding.

Groundwater Model Structure

I reviewed the groundwater model and model code to mostly consider that which would affect indirect effects on the wetlands. For this review, I considered Foth (2015) and Foth (2017). Foth (2017) is a response made to comments made by the agency.

The model domain, hydrologic units and model layers are appropriate. The model domain extends to natural boundaries such as groundwater divides or rivers. There are four major hydrologic units, the Quaternary alluvium, sandstone, and deeper bedrock. The deep bedrock is divided into two units, with one for weathered and another for unweathered conditions. The layering is appropriate, with each layer representing an entire or portion of a given formation, without blending two or more formations within the same layer. The model divides the sandstone into three layers over the area in which it is present, east of the Menominee River. The structure appropriately pinches out the sandstone in layers 2 through 4 as well.

The model uses appropriate boundary conditions on the domain boundary only in layer one, where it assumes no-flow conditions occur where there is a topographic (assumed to also be a groundwater) divide and a RIVER boundary where there is a river. Foth (2015) presents no data or information to suggest that the groundwater divide does not extend to deeper layers, therefore a no flow boundary should be used in all layers beneath a topographic (groundwater) divide. Groundwater does not flow through a divide, therefore the modeler should have used a no flow boundary.

Rather, Foth (2015) used a constant head (CH) boundary in layers 5 through 7 wherever layer 1 had a no flow boundary, therefore groundwater could enter or leave the model domain through the divide. Even in their response, Foth explains that no flow boundaries should have been used. “No Flow Boundary Conditions are commonly used at locations where an aquifer ends and there is no flow perpendicular to the boundary, or at groundwater divides, again where there is no flow perpendicular to the boundary” (Foth 2017, p 2, 3). Through the remainder of the model layers, they should have used no flow boundaries because a divide is likely observed throughout the model domain unless there is evidence of fracture flow or other flow into the domain.

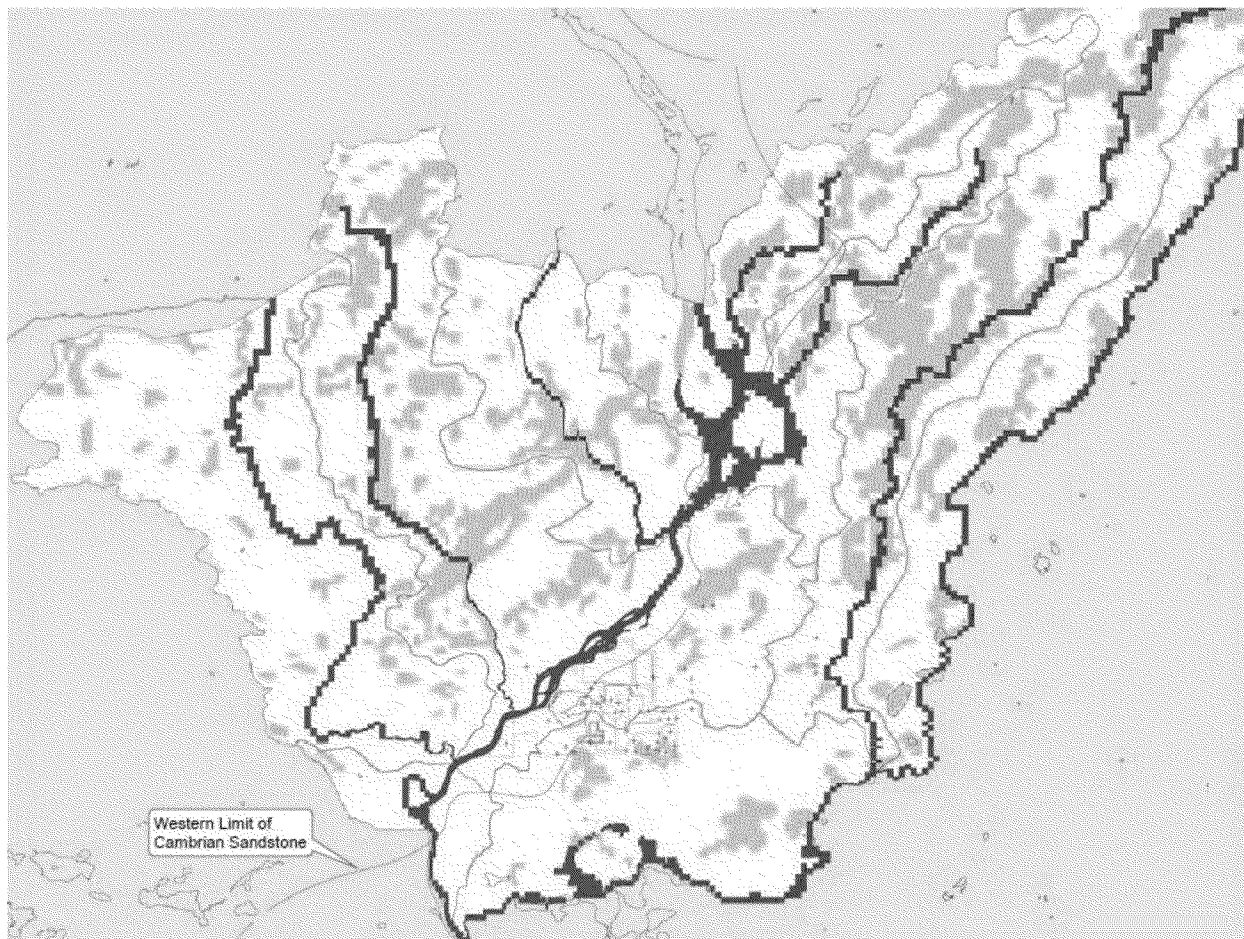
Foth should similarly have used a no flow boundary in the layers beneath the RIVER boundary on the edge of the domain. A losing river coincides with a groundwater divide because it provides recharge to the domain. In a gaining river, as is likely in this area, the groundwater flow paths would slope toward the river throughout the model domain; flowpaths at depth would curve upward to discharge into the river. Groundwater from one side of the river would not mix with groundwater on the other side because the upward flow would create an effective no flow boundary. A no flow boundary below layer 1 would force the groundwater flow to curve upward to discharge into the RIVER, as occurs naturally. Rather, in layers 2 through 7, Foth (2017) used CH boundaries beneath the river boundaries which would allow flow to either enter or leave the domain without resistance.

The CH head on the boundaries was set equal to contoured groundwater table elevations (Foth 2017, p 10). The CH will therefore force the model to simulate head levels equal to the observed heads near the boundary. A CH will maintain the head at a set elevation by providing whatever flow is necessary to the model domain. If the flow is low, the only error could be the failure to simulate discharge to the river, leading to an underestimate in that discharge. However, if there is significant flow across a CH boundary that should have little flow, the boundary could mask a problem. Foth does not even present the flow through the CH, so the casual reader of the report cannot assess whether there is an error. I analyze the water balance for the model below, using the model files. The CH boundaries allow a flow through the model domain, which increases the overall flux and affects the model parameterization.

Foth (2017) claims that “boundary conditions were assigned along the model perimeter where they are required in order to allow solution of the finite difference equations” (Foth 2017, p 10). This suggests that the modelers had difficulty making the model simulation converge, so they used a CH to force convergence. Their justification, “[b]ecause the watershed boundaries were assumed to correspond to groundwater divides only for the Quaternary deposits, these surface features were not used to define internal or perimeter boundary conditions for the deeper layers ...” (Id.). As noted above, CH could provide flow to the model domain at locations where there is none as it forces the heads to be as observed in some locations.

Figure 3 shows boundary conditions in layer 1. The green areas are River boundaries used to simulate wetlands. I verified that the model does not include recharge, a specified flux into the model domain, in the wetlands, so the method prescribed for simulating flow from the wetlands would simulate recharge from them. Recharge would occur only if the water level falls below the specified bottom of the River boundary. The total discharge is 56,119 m³/d to reach 11 (based on analysis using GWVistas), the River boundary reach simulating wetlands.

Perusal of the boundary using GWVistas shows a mixture of positive and negative flows to different model cells.



*Figure 3: Snapshot of Foth (2017) Figure * showing boundary conditions in layer 1. The blue is river boundaries, both on south and east boundary and internal to the model. The green represents wetlands, also simulated using the river package.*

Model Calibration

Foth calibrated the groundwater model only in steady state mode. Steady state calibration involves adjusting the parameters so that a steady state simulation gives water levels and simulated fluxes that equal the target, or observed, values. Foth used only groundwater elevations, not estimated or measured fluxes, and therefore the model is not unique.

The model is not unique because the calibration uses only groundwater level targets. Foth (2015) Table 4-4 shows good calibration statistics considering groundwater level observations only. But there is no consideration of whether discharge to the river is correct. Total discharge

to rivers and wetlands would equal the sum of total recharge and inflow from constant head boundaries. The set of parameters determined in the calibration would be different if the flux through the system changes. In other words, it is possible to calibrate any flow through the domain to the observed head values. Therefore, because the flow is not constrained, the model is not unique.

As noted above, the CH boundaries on the domain boundary would provide groundwater flow across a groundwater divide which would not occur. The flow analysis below shows the CH boundaries add a substantial flow beyond that which would have naturally recharged within the model domain, meaning that more simulated groundwater flows through the system and discharges to the rivers than actually occurs (Foth does not compare flow to the rivers to measured values.). To allow more water to flow while matching observed groundwater levels during calibration, the conductivity would have to be higher than if the flow was less (more conceptually accurate). This causes the model to have conductivity values that are too high.

The plot of modeled v observed groundwater elevations shows observations that scatter reasonably around the 1:1 line (Foth 2017, Figure 4-6). However, there is no map showing observation wells or residuals. It is not possible to assess spatial biases that could be apparent on the ground.

There is no transient calibration, so the storage coefficients were simply taken from textbook values.

Steady State Water Balance

Foth did not consider water balance as part of their calibration, as noted above, but I consider it in detail here. Using the water balance function in GWVistas, I considered the water balance for the entire model domain and individual layers in steady state conditions (Table 1). Recharge provides about 59,940 m³/d to the domain, and river inflow provides about 15,424 m³/d. The river inflow would be from reach 11, the wetlands (Figure 3), because the River boundaries that represent the river are all discharge points for groundwater (as can be seen from the groundwater contour maps, Foth (2015) Figures 2-7 and 2-8), meaning those rivers provide no flow to the model domain.

CH boundaries provide an inflow of 35,590 m³/d and an outflow of 12,432 m³/d. The CH inflow is more than 30% of the total inflow to the model domain. This is flow that crosses the boundaries into layers 2 through 7 (Table 1). This is a very large flux to add to the domain at depth without justification based on observed data or even based on a conceptual flow model (CFM). The large majority of the flow is through boundary reach 1, which is the CH along the

north edge of the project area (16,135 m³/d net inflow). In summary, CH boundaries provide up to 30% extra flow to the water balance of the domain, and the majority is from CH boundaries in layers 2 through 4 under the river on the north edge of the domain.

The effect of this additional flow to the model domain is to increase the hydraulic conductivity beyond what would otherwise occur. This is because the model in steady state balances inflow and outflow, so up to an additional 35,590 m³/d discharges to river boundaries, either wetlands or rivers, inappropriately. The CH flow makes up much of the difference between recharge and discharge to rivers (Table 1). The extra flow causes higher conductivity values during calibration.

Table 1: Water balance for steady state conditions, for the entire domain and by layer to layer 5. CH is constant head. All flows are m³/day

Steady State	Boundary	In	Out	Error
Domain	CH	35590	12432	
	River	15424	98739	
	Recharge	59940		
	Total	110954	111171	-0.00196
Layer 1	Top			
	Bottom	57881	29270	
	CH			
	River	15424	98739	
	Recharge	54691		
	Total	127996	128009	-0.0001
Layer 2	Top	29271	57881	
	Bottom	28325	22904	
	CH	21194	2751	
	River			
	Recharge	4692		
	Total	83482	83536	-0.00065
Layer 3	Top	22905	28325	
	Bottom	18820	15761	
	CH	4580	2359	
	River			
	Recharge	40		
	Total	46345	46445	-0.00216
Layer 4	Top	15761	18820	
	Bottom	11655	11241	

	CH	4307	2701	
	River			
	Recharge	32		
	Total	31755	32762	-0.03171
Layer 5	Top	11241	11655	
	Bottom	374	378	
	CH	5396	4505	
	River			
	Recharge	484		
	Total	17495	16538	0.054701

Table 1 also shows the percent error by layer. Water balance in layers 4 and 5 had 3.1 and 5.5% errors in water balances. This indicates the model has localized water balance problems, although they apparently did not lead to an overall model convergence problem.

Simulation of the Project

Mine simulation was essentially just a simulation of pit dewatering. Foth (2015) simulated dewatering using DRAIN boundaries within the pit outline. Foth specified elevations in each DRAIN boundary on a yearly basis. This means that on a yearly basis the boundary elevation changed significantly at the beginning of each time period. In other words, specified conditions for each boundary take effect at the beginning of each stress period. This is a substantial instantaneous stress applied to the model. Based on my experience, this would have caused model convergence errors. Foth used stress periods of 365.25 days with 120 time steps and a time step multiplier of 1.5. The first time step for each period would have been extremely small. Foth specified within GWVistas a flag that causes the model simulation to move to the following step whether or not convergence was reached, which means that some of the simulation may have significant water balance errors.

In layers 1 through 4, Foth set the DRAIN heads equal to the layer bottom elevation in period 1 and held it constant for the remainder of the simulation. In layer 5, Foth set the DRAIN head equal to the layer bottom in period 2 and held it constant for the remainder of the simulation.

To improve my ability to interpret the analysis, I switched the 365.25 day stress periods to 20 time steps with a time step multiplier of 1.2. By comparing the mass balance for the end of each period to that for the Foth time-stepping, I conclude the model continues to simulate the DRAINS as intended by Foth, but there may be larger mass balance errors at some time steps.

My adjustments allowed me to output hydrographs for specific reaches and to determine mass balances for periods less than one year.

Changing the analysis to 20 time-steps provided an understanding of how the model handles fluxes near the pit. Figure 4 is the water balance for all seven layers for a polygon drawn within the GWVistas framework on the pit boundary. The end of period mass balance values are very similar to those determined for Foth's model runs. Figure 4 shows that dewatering equals a combination of water released from storage and groundwater inflow to the pit area. At the beginning of each stress period, the rate of flux released from storage would peak and then settle to close to zero by the end of the period. The peak in storage release is due to the step lowering of the DRAIN water level as described above. The inflow to the area from all directions was relatively constant through time. Analysis of the mass balance by layer shows that the inflow to the pit area and the level from which the DRAIN removes water becomes deeper with years, as would be expected.

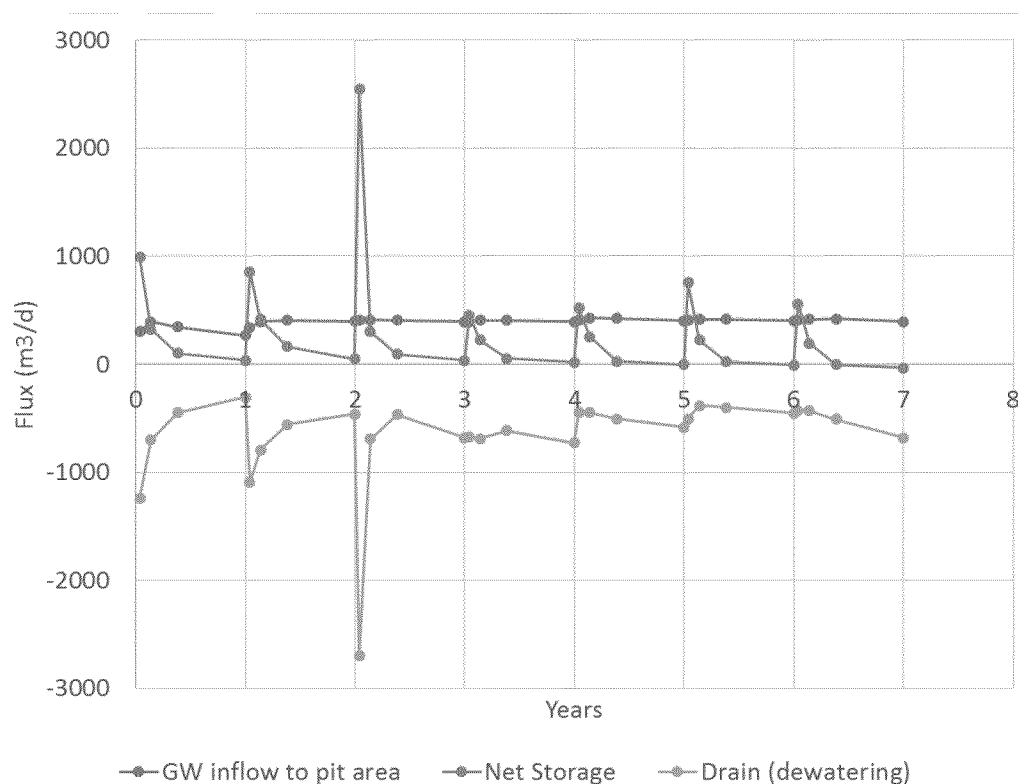


Figure 4: Water balance for the pit. GW inflow is the net of flows recorded as in and out from the east, west, north and south directions.

The RIVER boundaries as used for wetlands on the site limit the drawdown around the site. Steady state or pre-development groundwater contours form a groundwater ridge just south of

the proposed pit (Figure 5 and Figure 2-7 in Foth 2017). RIVER boundaries yield water to the aquifer based on the gradient between the water level in the wetland and the water table and conductance of the boundary. As dewatering lowers the water table, the gradient increases so discharge through the bottom of the boundary also increases. If the water table lowers sufficiently that there is a disconnect between the boundary (the bottom of the wetland) and the water table, the gradient becomes 1. Foth (2017) described that the flow at this point would equal the recharge as simulated around the model domain.

Drawdown contours curve around the wetlands, a result of the boundary discharging water to the groundwater table (Figure 6). The wetlands along the south part of the drawdown (Figure 6) somewhat limit the southward expansion of the drawdown cone. Wetlands northeast of the project site also limit the expansion. The influence of the wetlands extends into deeper layers. Drawdown in layer 2 is similar to that in layer 1, except for the dry areas (Figure 7).

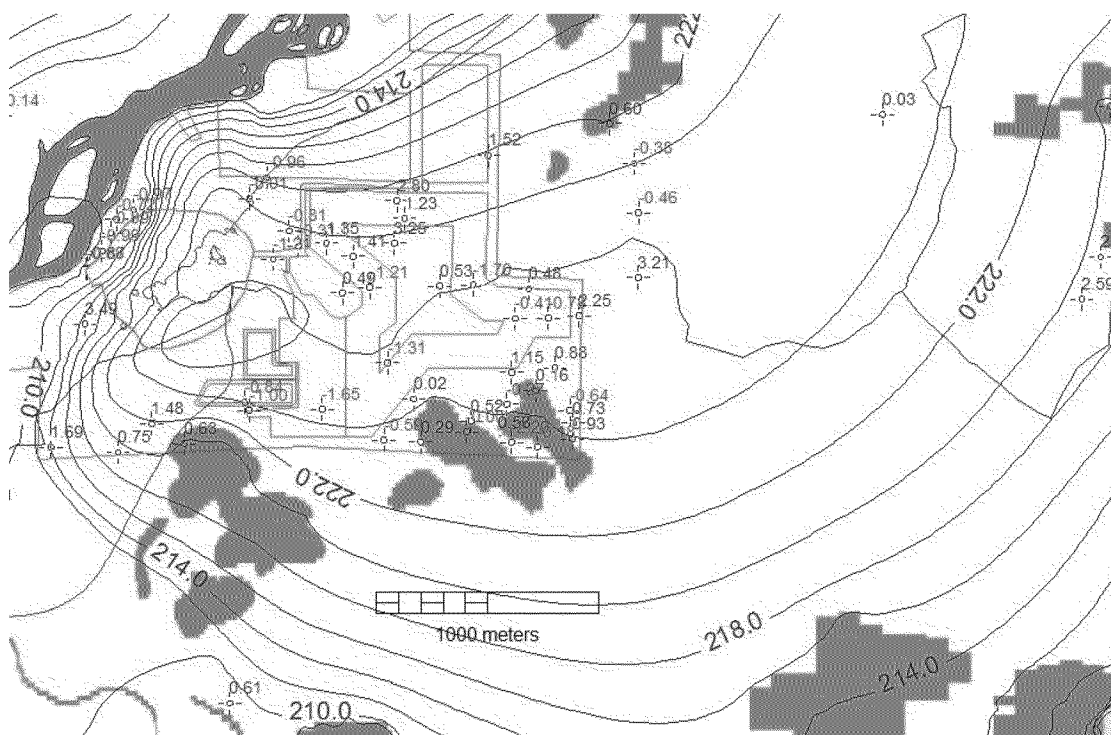


Figure 5: Screen capture of layer 1, steady state groundwater contours. The green areas are RIVER boundaries. The pit is outlined in green near the portion of the river with islands.

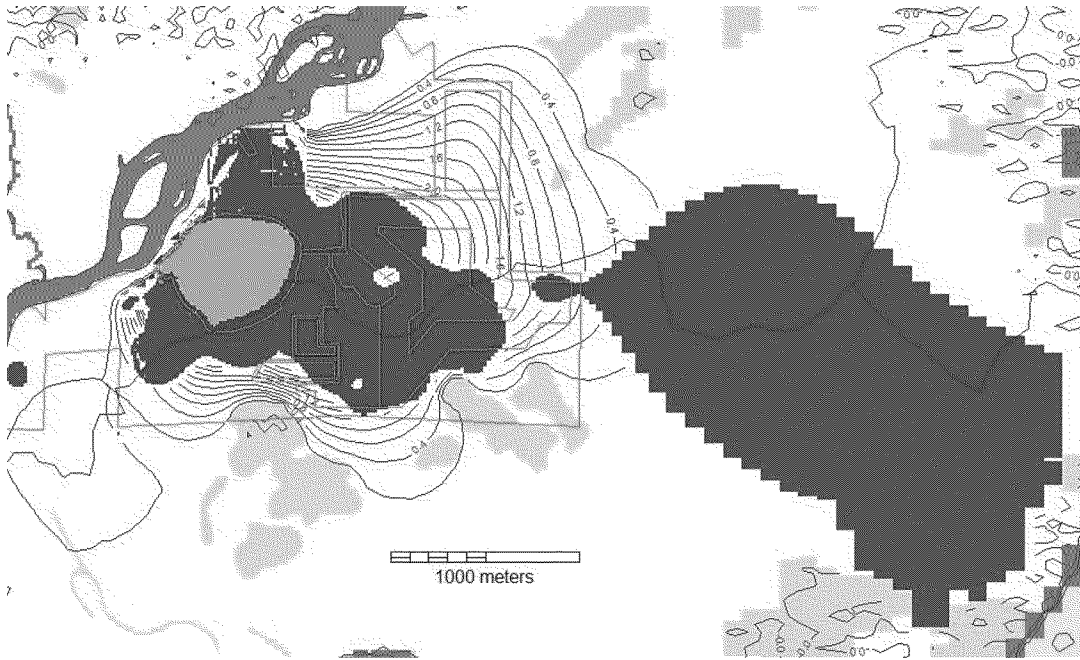


Figure 6: Screen capture of layer 1, end period 7, show drawdown contours. Green is RIVER boundaries representing wetland, yellow is DRAIN boundaries at the pit and purple areas are dry cells.

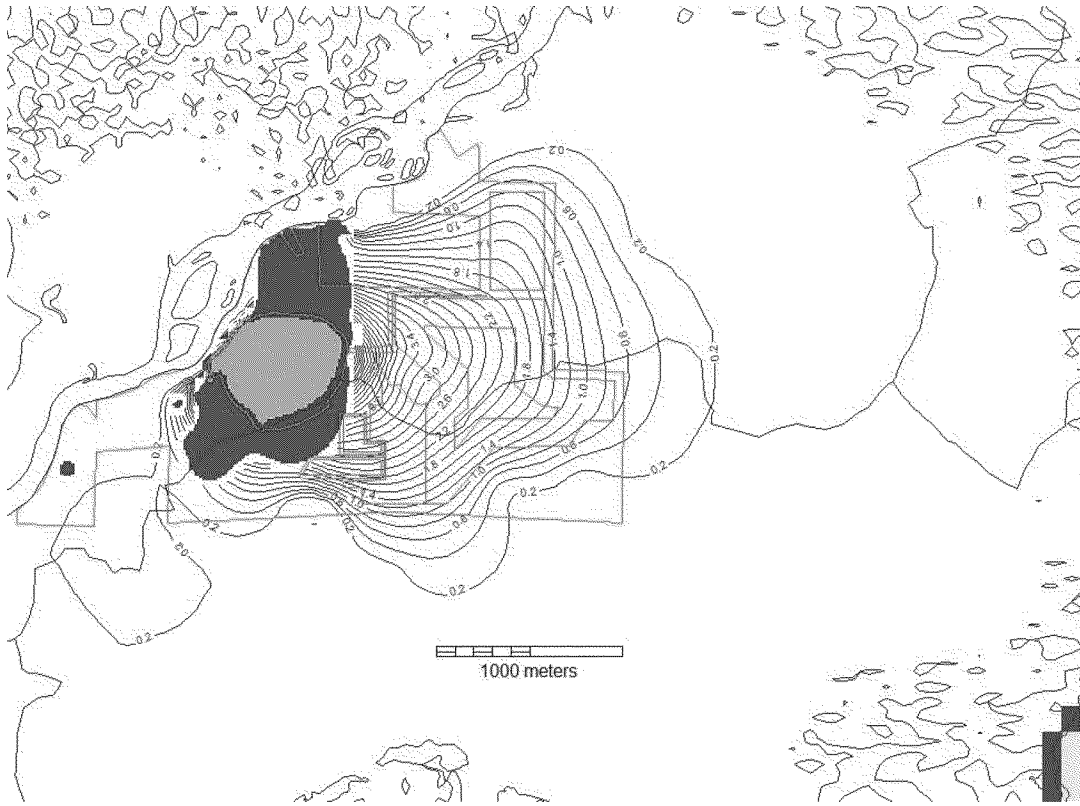


Figure 7: Screen capture of layer 4, end of period 7, showing drawdown contours. Yellow is the DRAIN for dewatering and purple areas are dry cells.

To consider the effect that wetlands have in maintaining the groundwater level, I considered one wetland area just south of the project site as outlined in Figure 8. That figure shows the drawdown contours bending around the wetland area. Drawdown within the wetland is near zero. Using the GWVistas mass balance function, I determined the water balance hydrographs for the seven-year dewatering period (Figure 9). Storage changes are tiny because there is no drawdown within the area. Inflow net is the sum of groundwater flux into the area from all directions and all layers. River in and river out are fluxes into and out of the model water balance. The difference is approximately the inflow net to the area. That River out is a substantial flux shows that there is a significant interchange of surface and groundwater in the model in this area, and presumably other River boundaries that represent wetlands. The RIVER boundary therefore maintains the groundwater level. I also considered flux from individual cells, and some had flux rates as high as the equivalent of between 6 and 7 in/y, the recharge rate, as indicated by Foth (2017).

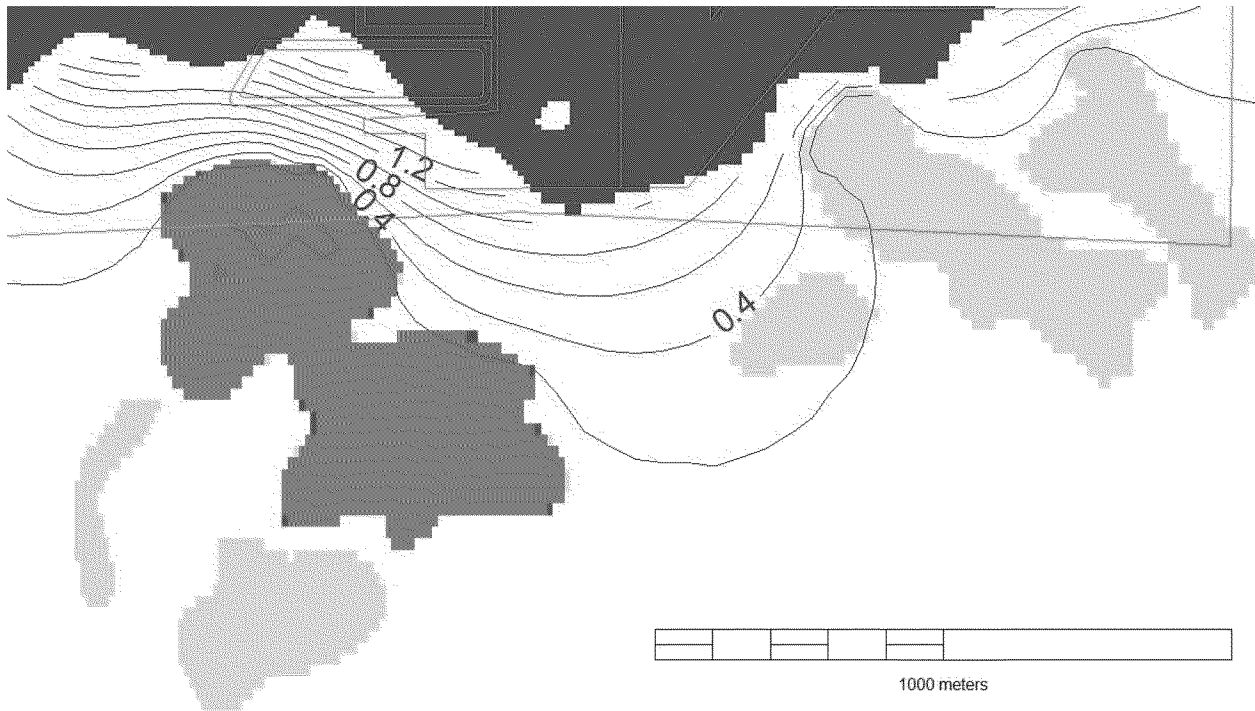


Figure 8: Detailed drawdown around a specific wetland area, WL-2b. Layer 1 at the end of year 7. The brown is the wetland over which a detailed water balance will be determined.

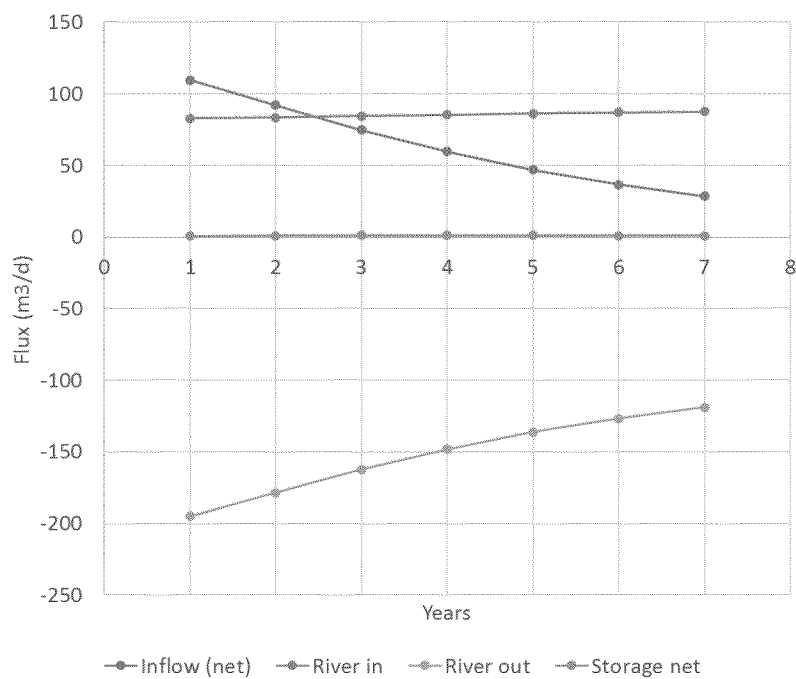
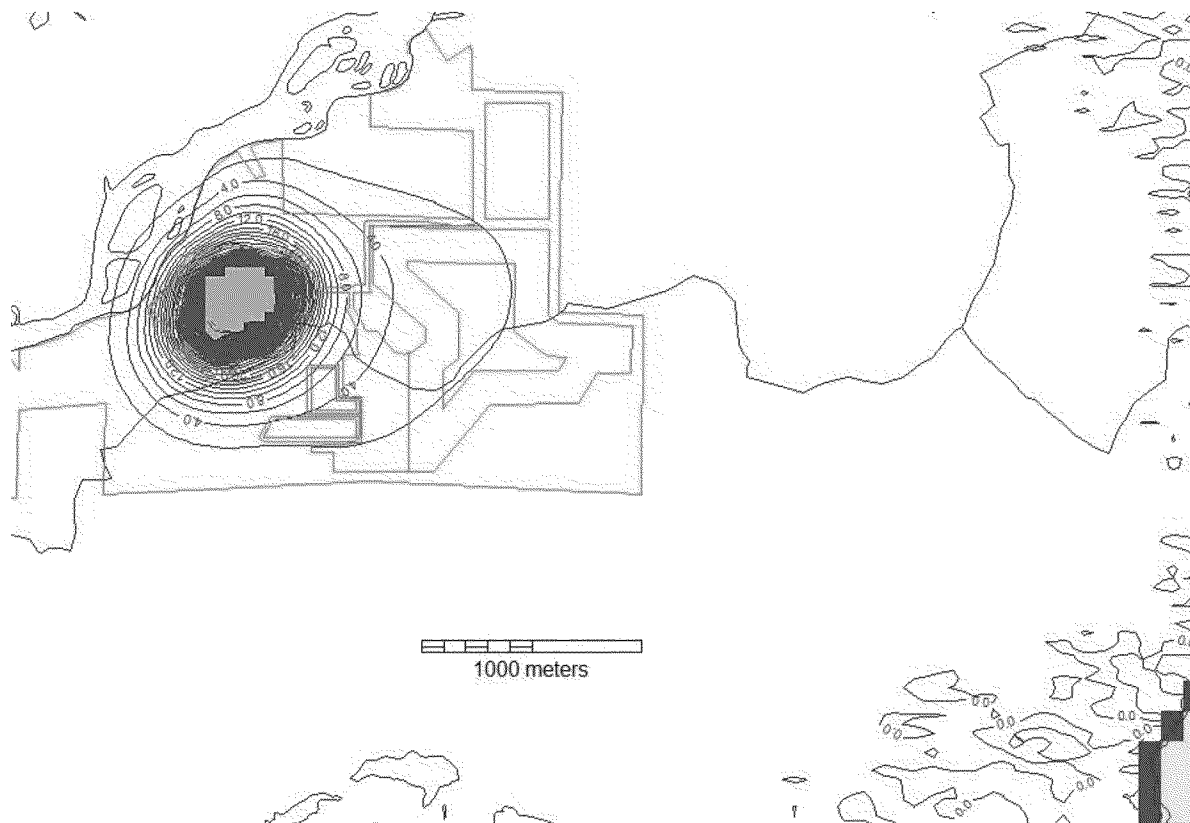


Figure 9: Water balance for the polygon region in Figure *, with fluxes recorded for the end of the year.

The conceptual model of the hydraulic connection between wetlands and groundwater is wrong. As described, RIVER boundaries, as used to simulate wetlands, can provide up to the full recharge rate, based on the conductance being set so that at a 1:1 gradient the flux would equal recharge. This presumes the conductivity through the bottom of the wetland is similar to the conductivity within the upper layer of the alluvial formation. At the wetland in Figure 8, horizontal and vertical conductivity equals 1.49 and 0.2 m/d, respectively, which is similar to the $K=1$ m/d used to estimate conductance in the RIVER boundary package (as determined from the GWVistas model file). Setting conductivity equal to that in the surface soil layer ignores the sediment that would accumulate at the bottom of a wetland which would likely form a skin on the bottom of the wetland that would impede seepage into the groundwater.

Without the seepage from the wetland, drawdown would expand further and increase the amount of indirect impacts to the wetlands.

At depth, in layer 6, drawdown is more elliptical because at this point the dewatering DRAINS are drawing from the bedrock. In fact, by year 7, most dewatering is from the bedrock, which has a very low conductivity. The low conductivity leads to very steep water table and limits the extent of drawdown at depth. In layers 5, 6, and 7, the conductivity is less than 4×10^{-2} m/d. The river also apparently limits the drawdown extension to the west.



CH boundaries surround the model domain, and may provide too much water to the steady state water balance, as described above. However, during transient simulation of the mine dewatering, neither inflows nor outflows through the CH changed more than a couple m^3/d , so the dewatering stress does not approach the model boundaries and these boundaries do not provide water to support the water levels.

Conclusion

The application acknowledges direct impacts to 11.22 acres and indirect impacts to 17.17 acres of wetlands. The review presented in this memorandum shows that indirect impacts will occur to far more than 17.17 acres because the modeling underestimates the extent of the groundwater drawdown. The Back Forty mine will have much greater indirect impact on wetlands than acknowledged in the permit application.

References

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